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46 **Differences in step characteristics and linear kinematics between**

47 **rugby players and sprinters during initial sprint acceleration**

48   The initial steps of a sprint are important in team sports, such as rugby, where

49   there is an inherent requirement to maximally accelerate over short distances.

50   Current understanding of sprint acceleration technique is primarily based on data

51   from track and field sprinters, although whether this information is transferable to

52   athletes such as rugby players is unclear, due to differing ecological constraints.

53   Sagittal plane video data were collected (240 Hz) and manually digitised to

54   calculate the kinematics of professional rugby forwards (n = 15) and backs (n =

55   15), and sprinters (n = 18; 100m PB range = 9.96 s to 11.33 s) during the first

56   three steps of three maximal sprint accelerations. Using a between-group research

57   design, differences between groups were determined using magnitude based

58   inferences, and within-group relationships between technique variables and initial

59   sprint acceleration performance were established using correlation. Substantial

60   between-group differences were observed in multiple variables. Only one

61   variable, toe-off distance, differed between groups (d = -0.42 to -2.62) and also

62   demonstrated meaningful relationships with sprint performance within all three

63   groups (r = -0.44 to -0.58), whereby a stance foot position more posterior relative

64   to the centre of mass at toe-off was associated with better sprint performance.

65   Whilst toe-off distance appears to be an important technical feature for sprint

66   acceleration performance in both sprinters and rugby players, caution should be

67   applied to the direct transfer of other kinematic information from sprinters to

68   inform the technical development of acceleration in team sports athletes.

69   Keywords: *biomechanics; constraints; rugby union; sprinting; technique*

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Introduction

Sprint acceleration is an important performance feature in team sports such as rugby, where the typical sprint time is between one and three seconds (Deutsch, Kearney, & Rehrer, 2007; Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). However, the majority of the current understanding of acceleration technique is from studies of track and field sprinters (e.g. Bezodis, Salo, & Trewartha, 2014; Bezodis, Salo, & Trewartha, 2015; Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2013; Ettema, McGhie, Danielsen, Sandbakk, & Haugen, 2016; Jacobs & van Ingen Schenau, 1992; Mero, Luhtanen, & Komi, 1983; Morin et al., 2015; Nagahara, Matsubayashi, Matsuo, & Zushi, 2014; Rabita et al., 2015), and the techniques adopted by high performing sprinters have been used for the development of general technical models during the initial steps of a sprint (Mann & Murphy, 2015). This information is potentially attractive to coaches of athletes in team sports since it is based on the fastest of all athletes and may be used to help inform their players' sprint training practices. However, this approach implies that an ideal movement template exists for all athletes and does not take into account the differing movement strategies which may emerge from the interaction of divergent constraints imposed (Newell, 1986; Saltzman & Kelso, 1987).

The constraints thought to influence movement have been separated, by Newell (1986), into three distinct categories – task, environment and organismic (hereafter referred to as 'performer'). Variations in technique and movement patterns can therefore emerge between team sport athletes (such as rugby players) and sprinters as a function of differing interacting constraints (Davids, Button, & Bennett, 2008; Newell, 1986). Although the broad goal of maximal linear sprinting for sprinters and rugby players during the initial steps is the same (i.e. to cover as much distance in as short a

99   time as possible), different task constraints exist due to sprint start conditions. The block

100   exit (sprinters) and standing (rugby players) start conditions, for instance, require

101   different body segment orientations which may influence techniques adopted in the

102   subsequent steps. The environment in which each group performs also differs. For

103   example, rugby is typically played on a grass surface, whereas sprinters compete on a

104   running track. Rugby players are also required to sprint as one of many match demands

105   in their training and competition environments. Differences in such demands are also

106   further evident across playing position in rugby (i.e. forwards versus backs; Quarrie,

107   Hopkins, Anthony, & Gill, 2013). Regarding performer constraints, movement

108   strategies adopted between athlete groups are also likely to be affected by physical and

109   anatomical constraints (Holt, 1998). Different performer constraints between sprinters

110   and rugby players, such as physical stature and body mass, musculoskeletal structure

111   (Lee & Piazza, 2009), and strength qualities may therefore result in different patterns of

112   movement. It is therefore important to understand which, if any, of the technical

113   features identified as important for sprint acceleration performance in a sprint-trained

114   population may be useful to inform the practices of coaches in attempts to enhance the

115   acceleration abilities of rugby players, given the differing constraints imposed.

116   There are likely many technical factors which influence initial sprint

117   acceleration performance. In fact, spatiotemporal variables, including step length and

118   step rate (the product of which determines step velocity) have received substantial

119   attention in the literature (e.g. Debaere, Jonkers, & Delecluse, 2013; Lockie, Murphy,

120   Schultz, Jeffriess, & Callaghan, 2013; Mackala, Fostiak, & Kowalski, 2015; Mann &

121   Murphy, 2015; Mero, Luhtanen, & Komi, 1983; Murphy, Lockie, & Coutts, 2003;

122   Nagahara, Naito, Morin, & Zushi, 2014; Rabita et al., 2015). Despite this coverage,

123   there remain conflicting perspectives on the importance of step length and step rate

124   during the initial steps of a sprint. For instance, in field sport athletes, higher step rates

125   were reported during the first three steps for a faster group (time to 15 m) compared

126   with a slower group (Murphy, Lockie, & Coutts, 2003), yet in 39 soccer players,

127   running speeds over the first four steps of a sprint were positively correlated with

128   average step length ($r = 0.60$; $p < 0.001$), but not average step rate (Nagahara, Takai,

129   Kanehisa, & Fukunaga, 2018). Moreover, neither step length or step rate of sprinters

130   were significantly correlated with 10 m sprint performance from a block start (Debaere,

131   Jonkers, & Delecluse, 2013). In addition to these mixed findings, information on the

132   determining factors of step length and step rate (Hay, 1994; Hunter, Marshall, &

133   McNair, 2004) is also sparse.

134   Due to the limited information available during the initial steps and conflicting

135   findings on the relative importance of step length and step rate to sprint performance,

136   establishing the importance of specific technical features for sprint acceleration is

137   currently challenging for a coach. This is further compounded by different measures

138   used (e.g. absolute or relative), study designs adopted (e.g. correlations or group

139   comparisons) and disparities between how acceleration performance is quantified,

140   which may explain some of the contradictions (Bezodis, Salo, & Trewartha, 2010).

141   Furthermore, due to the aforementioned inherent differences in the tasks, environments,

142   and performer constraints of rugby players' sprint acceleration compared with that of

143   sprinters, the relevance of the available information on the technical features deemed

144   important for performance in sprint-trained populations for enhancing the acceleration

145   abilities of performers in team sports (e.g. rugby) is unknown. Therefore, a direct

146   comparison between groups, with start conditions representative of their respective

147   environments and standardised measures of the technical features of interest and sprint

148   performance in the initial steps, is warranted. The purpose of this study was to

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149   investigate differences in step characteristics and linear kinematics between professional

150   rugby players and sprinters during the initial steps of acceleration, and determine how

151   each variable of interest relates to initial sprint performance within each group. We

152   hypothesised that: 1) substantial differences in technique would be evident between

153   sprinters and rugby players; 2) relationships between specific technique variables and

154   initial sprint acceleration performance would be consistent across each group.

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156   **Methods**

157   *Participants*

158   Eighteen male sprinters (mean ± *SD*: age 21 ± 4 years; stature 1.80 ± 0.10 m; body mass

159   75.7 ± 5.2 kg; 100 m personal best (PB) 10.60 ± 0.40 s, range 9.96 - 11.33 s) and 30

160   male professional rugby union players competing in the English Premiership, separated

161   into forwards (n = 15; mean ± *SD*: age 25 ± 4 years; stature 1.88 ± 0.06 m; body mass

162   111.6 ± 8.9 kg) and backs (n = 15; mean ± *SD*: age 26 ± 4 years; stature 1.81 ± 0.06 m;

163   body mass 88.6 ± 7.1 kg) volunteered to participate. All participants provided written

164   informed consent and the study protocols were submitted to, and approved by, the Local

165   Research Ethics Committee. At the time of testing, participants were injury free and

166   completed maximal effort sprint accelerations on a weekly basis as part of their routine

167   training. For the rugby players, data were collected during pre-season following 48

168   hours of abstinence from running, sprinting, and lower body strength training. For the

169   sprinters, data were collected during track training sessions just prior to the competition

170   phase of the outdoor season on days where the emphasis of training was to sprint

171   maximally.

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Procedures

175   The rugby players completed a 20 minute standardised warm-up, and then performed

176   three maximal effort 10 m sprints from a standing start (preferred foot forward), on an

177   outdoor acrylic surface, wearing a t-shirt, shorts and trainers, which was common

178   during speed and acceleration training at the stage of pre-season when data was

179   collected. Rest periods between each sprint were approximately 3-4 minutes. The

180   sprinters completed their regular warm-up routine overseen by their technical coach,

181   and then completed three maximal effort sprints over distances between 30 and 60 m

182   from blocks, on an outdoor running track, wearing spikes, shorts and either a vest or no

183   top. Rest periods between each sprint were between 7-12 minutes. Differences in the

184   sprint performance measure between the first and third sprint trials within each group

185   were less than the smallest worthwhile difference ($d = < 0.20$; Hopkins, 2002; Winter,

186   Abt, & Nevill, 2014), thus the different rest period durations used by rugby players and

187   sprinters did not bias any outcomes. For all sprints, video images (448×336 pixels)

188   were obtained at 240 Hz (Sanyo Xacti VPC-HD2000). The camera was positioned 20 m

189   from, and perpendicular to, the running lane to capture sagittal plane images from

190   touchdown and toe-off across the first three steps for each athlete within an

191   approximately 6 m wide field of view. A 5.00 m horizontal video calibration was

192   recorded at each data collection session.

193   The kinematic variables of interest were determined from the video frames

194   identified as the instants of touchdown (first frame the foot was visibly in contact with

195   the ground) and toe-off (first frame the foot had visibly left the ground) across the first

196   three steps of each sprint using 6× zoom in Kinovea (v.0.8.15). The human body was

197   modelled as 14 rigid segments: feet, shanks, thighs, hands, lower arms, upper arms,

198   trunk, and head. This required manual digitisation of the following: vertex of the head,

199   halfway between the supra-sternal notch and the 7th cervical vertebra, shoulder, elbow

200   and wrist joint centres, head of third metacarpal, hip, knee and ankle joint centres, the

201   most posterior part of the heel, and the tip of the toe.

202   The scaled digitised coordinates were exported to Excel (Microsoft Office

203   2013), where the following spatiotemporal step characteristics were determined: contact

204   time (s), flight time (s), step length (m; horizontal displacement between the toe tips at

205   adjacent touchdowns), step rate (Hz; the reciprocal of step duration, which was

206   determined as the sum of contact time and the subsequent flight time), and step velocity

207   (m/s; the product of step length and step rate). Whole body centre of mass (CM)

208   location was calculated using de Leva's (1996) segmental inertia data. This enabled the

209   calculation of touchdown and toe-off distances (m; horizontal distance between the toe

210   and whole body CM, with positive values representing the toe ahead of the CM),

211   contact length (m; horizontal distance the CM travelled during stance) and flight length

212   (m; horizontal distance the CM travelled during flight). All lengths and distances were

213   normalised to stature. Finally, average horizontal external power was calculated, based

214   on the change in kinetic energy as outlined by Bezodis et al. (2010), from the instant of

215   the first touchdown until the end of the third contact phase, and used as an objective

216   measure of sprint acceleration performance. In order to facilitate between-group

217   comparisons, average horizontal external power was normalised according to a

218   modification of the equation presented by Hof (1996) as used by Bezodis et al. (2010).

219

220   *Statistical analyses*

221   Test-retest intra-rater reliability of manual digitisation was determined using an

222   intraclass correlation coefficient (ICC 3,1) with 90% confidence intervals. The segment

223   endpoints at the instant of touchdown and toe-off, for ten participants selected at

224   random, were digitised on two separate occasions, one week apart.

225   The data obtained for each kinematic variable were averaged across the three

226   sprint trials of each participant. Differences between group means (sprinters, backs, and

227   forwards) for all step characteristics and kinematic variables were analysed using a

228   magnitude-based inference approach (Hopkins, Marshall, Batterham, & Hanin, 2009).

229   Cohen's *d* (Cohen, 2013) was calculated between groups, with an effect size of 0.20

230   used to define the smallest worthwhile difference (Hopkins, 2002; Winter, Abt, &

231   Nevill, 2014). The magnitudes of these standardised differences were expressed relative

232   to the smallest worthwhile difference as follows: <0.2, trivial; 0.2, small; 0.6, moderate;

233   1.2, large; 2.0, very large and 4.0, extremely large (Hopkins et al., 2009). Confidence

234   intervals (90%) were calculated to measure the uncertainty of the effect sizes, and the

235   quantitative chances of finding between group differences in the variables tested greater

236   than the smallest worthwhile difference were assessed as follows: 25 - < 75%, possibly;

237   75 - < 95% likely; 95 - < 99.5%, very likely; > 99.5%, most likely (Hopkins et al.,

238   2009). If 90% confidence intervals included positive and negative values greater than

239   the smallest meaningful difference (where the chances of positive and negative value

240   differences are both >5%), the true difference was deemed unclear.

241   Each step characteristic and kinematic variable was then averaged over the first

242   three steps for each participant. These values were used to determine the relationships

243   of each technique variable with normalised average horizontal external power (NAHEP)

244   within each group using Pearson's product moment correlation coefficient (r).

245   Confidence intervals (90%) for the observed relationships were calculated to detect the

246   smallest clinically important correlation coefficient. The magnitude of relationships

247   were deemed unclear when confidence limits overlapped substantial positive and

248   negative values (r = ± 0.1) (Hopkins, 2002). The strength of relationships were defined

249   as (±): 0.35 (forwards and backs) and 0.31 (sprinters), unclear; 0.36 (forwards and

250   backs) and 0.32 (sprinters) to 0.50 moderate; 0.50 to 0.70, high; 0.70 to 0.90, very high;

251   0.90 to 1.00, practically perfect (Hopkins, 2002).

252

253   **Results**

254   Intraclass correlation coefficients between the first and second digitising occasions

255   indicated excellent (Portney & Watkins, 2000) intra-rater reliability for all step

256   characteristics and kinematic variables (ICC >0.90; CL 0.85-0.99).

257   Regarding acceleration performance over the first three steps, backs most likely

258   produced greater NAHEP than forwards, and the NAHEP of sprinters was most likely

259   greater than the forwards and backs, the magnitude of these differences were extremely

260   large and large, respectively (Figure 1). Of the spatiotemporal step characteristics, backs

261   very likely achieved greater step velocities (Figure 2a) compared with forwards, the

262   difference being moderate (d = 0.76 to 1.08; Table I). Sprinters very likely produced

263   step velocities higher than forwards of moderate magnitudes (d = 0.95 to 1.18; Table I),

264   although when compared with backs, the difference (in the same direction) was only

265   possibly evident and small at the third step (d = 0.06 to 0.49; Table I).

266

267   ****Figure 1 near here****

268   ****Table I near here****

269

270   The step rates (Figure 2c) of backs were likely (step one) and very likely (steps

271   two and three) greater than the forwards and of moderate magnitudes (d = 0.64 to 1.16;

272   Table I). Sprinters possibly (step one) and likely (steps two and three) achieved greater

273 step rates than the forwards. The magnitude of the differences were small and moderate,

274 respectively ($d = 0.28$ to 0.77; Table I). However, the sprinters' step rates were possibly

275 lower than those of the backs, with a small difference evident across all three steps ($d =$

276 -0.46 to -0.32; Table I).

277

278   ****Figure 2 near here****

279

280   The contact times (Figure 2d) of backs were likely shorter compared with

281 forwards in step one (moderately) and very likely shorter in steps two and three, where

282 the magnitudes of these differences were large and very large, respectively ($d = -2.67$ to

283 -1.00; Table I). Sprinters' contact times were consistently shorter than forwards and

284 longer than backs. Sprinters' contact times in the first step were possibly shorter (small

285 magnitude), and by the second and third steps very likely and most likely shorter

286 (moderate magnitudes), than those achieved by forwards ($d = -1.89$ to -0.47; Table I).

287 Likely differences between sprinters' and backs' contact times were evident in step one

288 (moderate magnitude) and possibly in steps two and three, of small magnitudes ($d =$

289 0.50 to 0.63; Table I).

290   The flight times (Figure 2e) of backs were possibly greater (moderate

291 magnitude) during the first and second steps compared with forwards and likely greater

292 (moderate magnitude) during the third step ($d = 0.37$ to 0.81; Table I). Differences in

293 flight times between sprinters and forwards were likely (sprinters producing moderately

294 greater flight times) for steps two and three ($d = 0.13$ to 0.76; Table I).

295   Backs likely produced greater step lengths (Figure 2b), which were moderately

296 different compared with forwards during the first two steps and possibly longer step

297 lengths of a small magnitude during step three ($d = 0.51$ to 0.75; Table I). Sprinters

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298 most likely produced longer step lengths compared with forwards and backs across each

299 step. The magnitude of the differences were large ($d = 1.36$ to 1.46; Table I) relative to

300 forwards, yet small and only possible in step one and moderate with likely differences

301 in steps two and three in relation to backs ($d = 0.52$ to 0.92; Table I).

302   Backs' contact lengths (Figure 2f) were possibly smaller during steps one and

303 three compared with forwards' ($d = -0.25$ and -0.33; Table I). Sprinters achieved contact

304 lengths which were possibly shorter compared with forwards in step one and longer

305 compared with backs in step three ($d = -0.40$ and 0.59; Table I). Backs likely achieved a

306 greater flight length (moderate magnitude) compared with forwards during the first step

307 and very likely greater flight lengths of moderate (step two) and large (step three)

308 magnitudes ($d = 0.87$ to 1.63; Table I). The flight lengths of sprinters were most likely

309 greater compared with forwards across all steps ($d = 1.41$ to 2.45; Table I). Sprinters'

310 flight distance was also greater compared with backs where possibly and likely

311 differences of small magnitudes were evident ($d = 0.38$ to 0.48; Table I).

312   Backs touched down with their toe more posterior to their CM than forwards

313 across each step (Figure 2h). During step one they were possibly different (moderate

314 magnitude), whereas the difference was likely and most likely during steps two and

315 three (large magnitude), respectively ($d = -1.19$ to -0.57; Table I). Sprinters' touchdown

316 distances (Figure 2h) were consistently more posterior across all steps relative to

317 forwards and backs. The difference was most likely large (step one) and very large

318 (steps two and three) compared with forwards ($d = -2.64$ to -1.92; Table I). Compared

319 with backs, the differences were most likely and large in magnitude (step one), very

320 likely and moderate in magnitude (step two), and likely and moderate in magnitude

321 (step three; $d = -0.89$ to -1.69; Table I).

322   At toe-off backs possibly (steps one and three) and most likely (step two)

323   positioned their toe more posterior relative to their CM position (Figure 2i) compared

324   with forwards (d = -1.22 to -0.42). The magnitude of this difference was small in steps

325   one and three and moderate in the second step. Sprinters most likely positioned their toe

326   more posterior relative to their CM at toe-off compared with forwards and backs, where

327   the difference was very large in each step (d = -2.62 to -2.05).

328   Regarding correlation coefficients, only toe-off distance consistently

329   demonstrated a meaningful relationship with NAHEP in each group (Figure 3h), the

330   magnitude of which was moderate for backs and large for forwards and sprinters (r = -

331   0.58 to -0.44). Moderate relationships were also observed between step length and

332   NAHEP (Figure 3a) in both forwards and sprinters (r = 0.39 and 0.45, respectively). In

333   the same two groups negative relationships between contact time and NAHEP (Figure

334   3c) were observed (r = - 0.39 and r = - 0.35, respectively). The step rate of sprinters was

335   moderately positively correlated to horizontal NAHEP (r = 0.44; Figure 3b), as was the

336   contact length (r = 0.46; Figure 3e) of forwards.

337

338   ****Figure 3 near here****

339

340   **Discussion**

341   The purpose of this study was to investigate the differences in step characteristics and

342   linear kinematics between professional rugby players and sprinters during the initial

343   steps of acceleration, and how each of these variables relates to initial sprint

344   performance. This provides information to enhance the understanding of how

345   knowledge of sprinters' acceleration techniques may be transferred to inform training

346   practices aimed at enhancing the acceleration abilities of rugby players. The main

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347   finding of this study was that there were multiple differences in the magnitudes of

348   various touchdown and toe-off kinematics between sprinters and rugby groups,

349   confirming our first hypothesis. However, only one technical feature (toe-off distance)

350   was consistently related to sprinting performance in all groups, and thus our second

351   hypothesis was largely rejected. There may therefore be limitations in how the available

352   information concerning the touchdown and toe-off kinematics and step characteristics

353   of sprinters can be used by coaches tasked with enhancing the acceleration abilities of

354   rugby players, possibly due to the different constraints imposed (Newell, 1986).

355   Sprinters achieved substantially greater levels of performance (NAHEP)

356   compared with forwards and backs, by 40% and 19%, respectively. This is explained by

357   their greater change in velocity from the beginning of the first contact phase to the end

358   of the third (sprinters = 3.26 ± 0.28 m/s; backs = 2.60 ± 0.26 m/s; forwards = 2.48 ±0.28

359   m/s), since less than 0.03 s separated the groups with respect to the time taken to

360   achieve this change. However, no substantial differences in absolute step velocity were

361   found between sprinters and backs until step three, where sprinters possibly reached a

362   higher step velocity ($d = 0.49$), because the backs entered the first step with a higher

363   velocity than the sprinters (3.61 ± 0.16 vs. 3.36 ± 0.31 m/s; forwards = 3.38 ± 0.26 m/s).

364   This is likely reflective of the differences in start conditions, where a longer distance

365   between the feet in the standing start may lead to a longer push-off phase (Salo &

366   Bezodis, 2004), thus affording the opportunity to produce higher impulse where the

367   rapid initiation of a sprint in response to an external stimulus (e.g. starter's gun) is not

368   required.

369   Sprinters consistently produced longer step lengths than backs, who also

370   achieved longer step lengths than forwards (Figure 2b), whilst backs achieved the

371   highest step rates in each step, followed by sprinters and then forwards (Figure 2c). The

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372 inconsistent findings of previous research as to the relative contribution of step length

373 and step rate to initial sprint acceleration performance (Debaere et al., 2013; Mackala,

374 Fostiak, & Kowalski, 2015; Murphy et al., 2003) is further compounded by the results

375 of the current study where positive moderate relationships of step length and step rate

376 with NAHEP in sprinters were found (r = 0.45 and 0.44), whereas only step length was

377 correlated to the NAHEP of forwards (r = 0.39) and no meaningful relationships of step

378 length or step rate with the NAHEP of backs were found (Figures 3a; 3b).

379   The differences in step length between groups were achieved primarily through

380 different flight lengths, but not contact lengths (Figure 2; Table I). However, the

381 location of the foot relative to the CM position was more posterior at both touchdown

382 and toe-off for sprinters compared with both rugby groups, and for backs compared

383 with forwards (Figures 2h; 2i). Smaller touchdown distances have been shown to be

384 related to a more forward-orientated ground reaction force (GRF) vector (Bezodis,

385 Trewartha, & Salo, 2015; Kugler & Janshen, 2010), which has been identified as a key

386 determinant of acceleration performance (Kawamori, Nosaka, & Newton, 2013; Kugler

387 & Janshen, 2010; Morin, Edouard, & Samozino, 2011; Morin et al., 2012). However, no

388 meaningful relationships between touchdown distance and NAHEP were evident in any

389 group in the current study, which may be explained by a number of factors. For

390 example, Bezodis et al. (2015) demonstrated the existence of a within-individual

391 curvilinear relationship between touchdown distance and NAHEP in the first stance

392 phase for an international–level sprinter, whilst vertical impulse production was found

393 to increase linearly as the foot was placed further forward relative to the CM . Limiting

394 how far posteriorly the foot makes contact relative to the CM may therefore be

395 important in producing sufficient vertical GRF to support bodyweight. Consequently, an

396 optimal touchdown distance is likely to exist for each individual influenced by varying

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397 constraints. For instance, greater vertical GRF will need to be produced with increased

398 body mass, therefore potentially requiring a greater touchdown distance (i.e. foot

399 positioned further forward of the CM). Additionally, the block start already positions

400 the sprinter's CM ahead of their feet (Mero, Luhtanen, & Komi, 1983) and the effect of

401 both running shoe worn and surface may also provide different opportunities for a

402 sprinter's maintenance of balance. The range of different constraints imposed on rugby

403 players (e.g. greater mass (performer constraint), standing start (task constraint), grass

404 surface (environmental constraint)) suggest that expecting them to touch down posterior

405 to their CM in the same manner as sprinters during the initial steps may not be feasible.

406 It may also be possible to manipulate GRF orientation through other technical

407 adjustments which combine to not affect the overall touchdown distance (Bezodis,

408 North, & Razavet, 2017). Further investigations of segmental and joint angular

409 kinematics during the initial steps of rugby players and how these are influenced by

410 performer constraints such as physical qualities (e.g. strength, anthropometrics), as well

411 as how they influence GRF orientation, may provide further insight into factors which

412 influence rugby players' sprint acceleration technique and performance.

413   Whilst touchdown distance was not related to sprint performance for any of the

414 groups, toe-off distance consistently was ($r = -0.44$ to -0.58). Having the stance toe

415 further behind the CM at toe-off was associated with increased NAHEP in all three

416 groups, and therefore appeared to be reflective of an effective push-off. A more

417 negative toe-off distance was also evident in sprinters compared with backs, who in turn

418 achieved more negative toe-off distances compared with forwards. The importance of

419 this technical feature does appear to transfer between sprinters and rugby players and a

420 CM further forward relative to the point of contact at toe-off during the first step has

421 previously been associated with higher propulsive impulse (Kugler & Janshen, 2010).

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422   Toe-off distance, and the body segment rotations used to achieve a greater toe-off

423   distance may be representative of an effective 'push-off' and therefore a function of

424   GRF orientation characteristics (Rabita et al., 2015), therefore warranting further

425   investigation. In the current study, sprinters produced longer contact times relative to

426   backs and may have used this to achieve a greater toe-off distance as a result (Kugler &

427   Janshen, 2010). While start position and footwear may again play roles in the ability to

428   achieve such a forward lean position, performer constraints may also be an important

429   consideration. For example, Lee and Piazza (2009) demonstrated, through computer

430   simulation, that the longer toes of sprinters (compared with non-sprinters) prolonged the

431   time of contact during a 'push-off' giving greater time for forward acceleration by

432   producing greater propulsive forces. However, it is possible to have a high impulse by

433   pushing-off for longer, but low acceleration if the magnitude of the impulse (and thus

434   change in velocity) is achieved primarily through spending a longer time generating

435   GRF rather than by generating greater GRF magnitudes. This may account for the

436   strategy of backs to produce higher step rates through shorter contact times whilst still

437   achieving superior sprint performance compared with forwards.

438   This study aimed to quantify the differences in step characteristics and linear

439   kinematics between professional rugby players and sprinters during the initial steps of

440   acceleration, and determine how each technique variable related to the initial sprint

441   performance of each group. Although we did not experimentally test each different

442   ecological constraint independently, the groups were observed in representative settings

443   to determine between group differences in their habitual environments. Therefore the

444   findings are relevant to practitioners working with rugby players to enhance initial

445   sprint acceleration performance. There were clear differences in touchdown and toe-off

446   kinematics between groups which are likely to have emerged, at least in part, as a result

447 of inherent differences in task, environment and performer constraints. Toe-off distance

448 was the only technical feature to differ between the groups which was also consistently

449 related to sprint performance within each group, and thus may be an important

450 consideration which can transfer to the sprint training practices of rugby players. Other

451 features of technique identified as potentially important for sprint acceleration

452 performance from the existing literature on sprint-trained athletes may not transfer

453 directly to rugby players.

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Table I. Effect sizes[a] (and their 90% confidence limits) for spatiotemporal step characteristics in each step between rugby backs and forwards, sprinters and rugby forwards, and sprinters and rugby backs.

Spatiotemporal step characteristics	Backs vs. forwards					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.08	0.52 to 1.65	0.92	0.43 to 1.41	0.76	0.22 to 1.31
Step rate (Hz)	0.64	0.11 to 1.17	1.45	0.52 to 2.38	1.16	0.51 to 1.81
Contact time (s)	-1.00	-1.54 to -0.46	-2.67	-3.37 to -1.97	-1.69	-2.21 to -1.16
Flight time (s)	0.37	-0.27 to 1.02	0.63	-0.11 to 1.38	0.81	0.03 to 1.58
Step length[b]	0.70	0.03 to 1.38	0.75	0.20 to 1.31	0.51	-0.08 to 1.11
Contact length[b]	-0.25	-0.80 to 0.30	0.12	-0.44 to 0.68	-0.33	-0.84 to 0.18
Flight length[b]	0.87	0.20 to 1.54	1.06	0.28 to 1.83	1.63	0.82 to 2.43
Touchdown distance[b]	-0.57	-1.10 to -0.03	-1.04	-1.74 to -0.34	-1.19	-1.76 to -0.61
Toe-off distance[b]	-0.56	-1.14 to 0.02	-1.22	-1.72 to -0.72	-0.42	-0.91 to 0.08

	Sprinters vs. forwards					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	1.18	0.54 to 1.83	0.95	0.40 to 1.51	1.18	0.65 to 1.71
Step rate (Hz)	0.28	-0.21 to 0.77	0.71	0.06 to 1.37	0.77	0.21 to 1.34
Contact time (s)	-0.47	-0.97 to 0.03	-1.89	-2.87 to -0.92	-1.31	-1.81 to -0.81
Flight time (s)	0.37	-0.27 to 1.02	0.70	0.10 to 1.30	0.76	0.20 to 1.32
Step length[b]	1.36	0.78 to 1.94	1.41	0.85 to 1.96	1.46	0.87 to 2.04
Contact length[b]	-0.4	-0.89 to 0.08	0.02	-0.61 to 0.64	0.09	-0.42 to 0.61
Flight length[b]	1.41	0.71 to 2.10	1.64	1.04 to 2.23	2.45	1.80 to 3.10
Touchdown distance[b]	-1.92	-2.40 to -1.44	-2.64	-3.41 to -1.87	-2.03	-2.66 to -1.41
Toe-off distance[b]	-2.53	-3.12 to -1.94	-2.62	-3.20 to -2.05	-2.05	-2.67 to -1.43

	Sprinters vs. backs					
	Step 1		Step 2		Step 3	
	ES	90% CL	ES	90% CL	ES	90% CL
Step velocity (m/s)	0.11	-0.57 to 0.78	0.06	-0.68 to 0.80	0.49	-0.07 to 1.05
Step rate (Hz)	-0.46	-0.99 to 0.07	-0.38	-0.87 to 0.12	-0.32	-0.85 to 0.20
Contact time (s)	0.63	0.10 to 1.16	0.58	-0.19 to 1.34	0.50	-0.05 to 1.05
Flight time (s)	-0.21	-0.80 to 0.39	0.04	-0.47 to 0.55	-0.03	-0.51 to 0.46
Step length[b]	0.52	-0.01 to 1.04	0.76	0.17 to 1.36	0.92	0.35 to 1.50
Contact length[b]	-0.18	-0.69 to 0.33	-0.11	-0.78 to 0.56	0.59	0.00 to 1.18
Flight length[b]	0.42	-0.18 to 1.03	0.38	-0.13 to 0.88	0.48	-0.03 to 0.99
Touchdown distance[b]	-1.69	-2.20 to -1.18	-1.18	-1.82 to -0.55	-0.89	-1.53 to -0.25
Toe-off distance[b]	-2	-2.60 to -1.41	-2.16	-2.90 to -1.42	-1.71	-2.21 to -1.20

[a]A positive/negative effect size depicts a greater/lesser magnitude of spatiotemporal step characteristics produced by the first group in their respective group comparison (e.g. a positive effect size under 'Backs vs. forwards' for step velocity would indicate that backs produced a higher step velocity compared with forwards in that step). The magnitude of differences (Cohen's d) were expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99, large; 2.0 to 3.99, very large; ≥ 4.0, extremely large.

[b]Normalised to participant's stature.
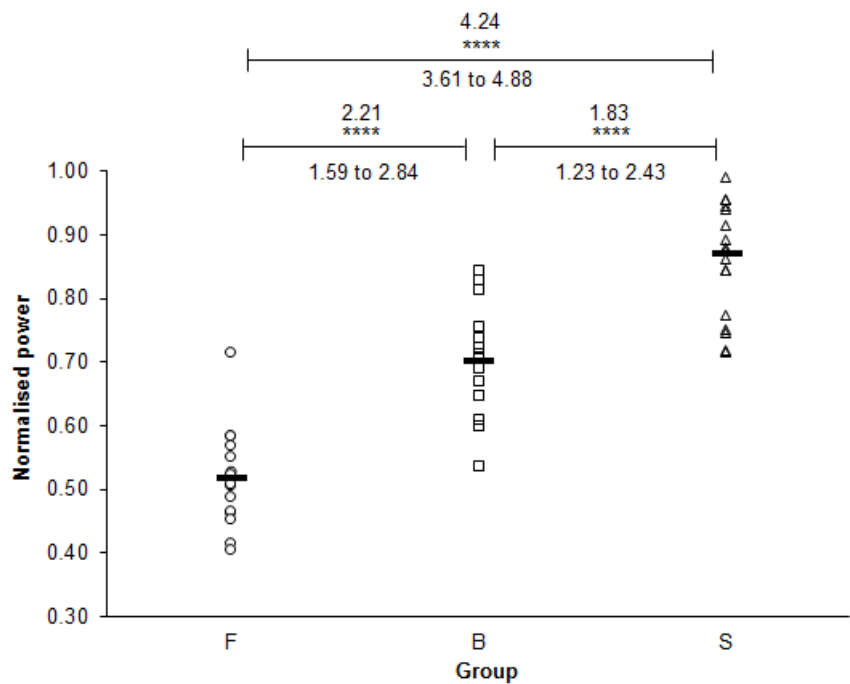
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600   Figure 1. Normalised average horizontal external power[a] for forwards (F), backs (B)
601   and sprinters (S) from first touchdown until the end of the third contact phase of a
602   sprint, and the effect sizes[b] (and their 90% confidence limits[c]) between each group.
603   Individual participant means are plotted, and the black bars represent group means. The
604   number of asterisks depict the quantitative chances of finding between group
605   differences: * = possibly; ** = likely, *** = very likely, **** = most likely.

606

607   [a]Normalised according to a modification of the equation presented by Hof (1996) as
608   used by Bezodis et al. (2010).

609

610   [b]Above the asterisks. A positive/negative effect size depicts a greater/lesser magnitude
611   of normalised average horizontal external power produced by the first group in their
612   respective group comparison (e.g. a positive effect size under 'Backs vs. forwards'
613   would indicate that backs produced higher normalised average horizontal external
614   power compared with forwards). The magnitude of differences (Cohen's d) were
615   expressed as: <0.20, trivial; 0.20 to 0.59, small; 0.60 to 1.19, moderate; 1.20 to 1.99,
616   large; 2.0 to 3.99, very large; ≥ 4.0, extremely large.

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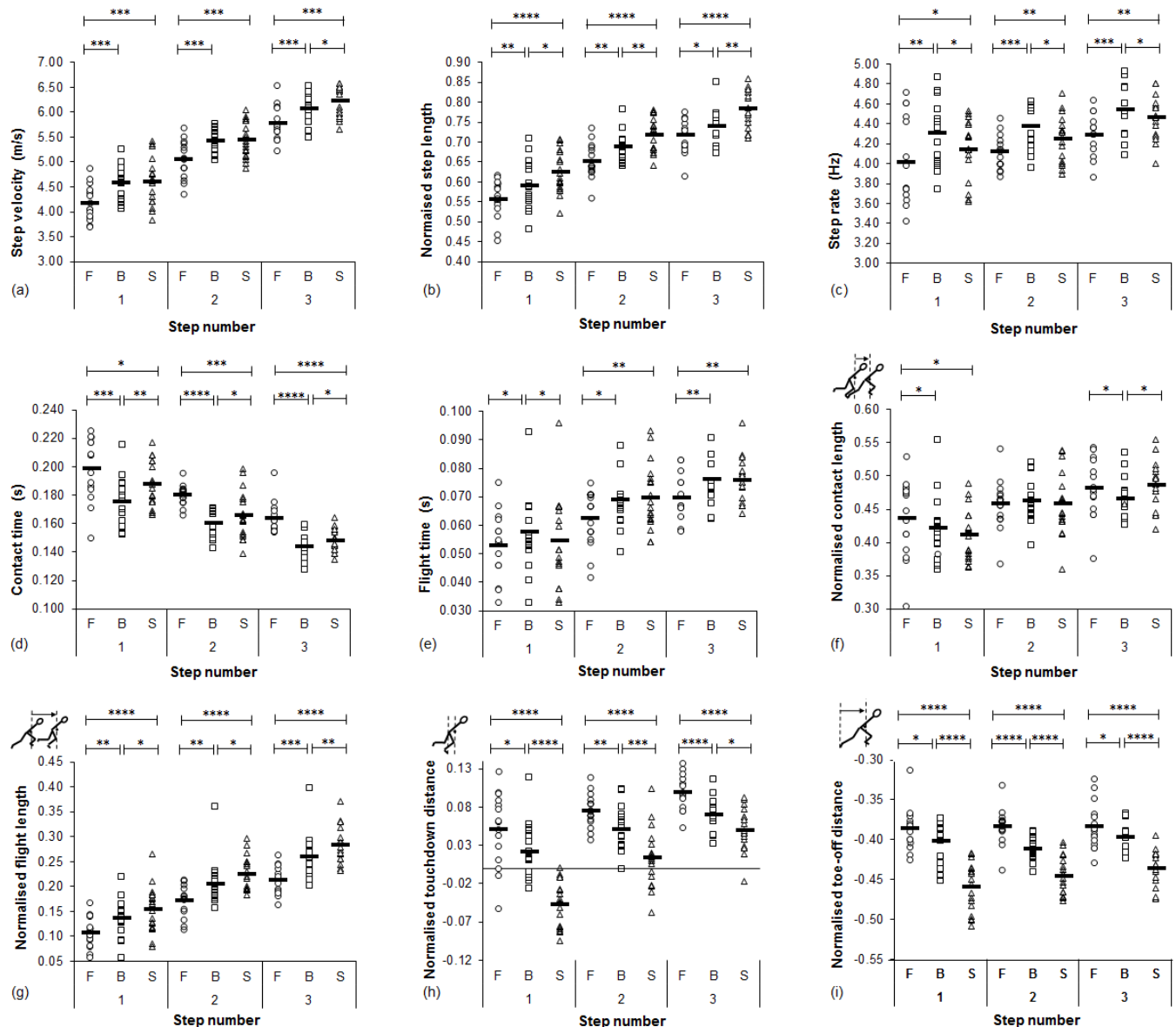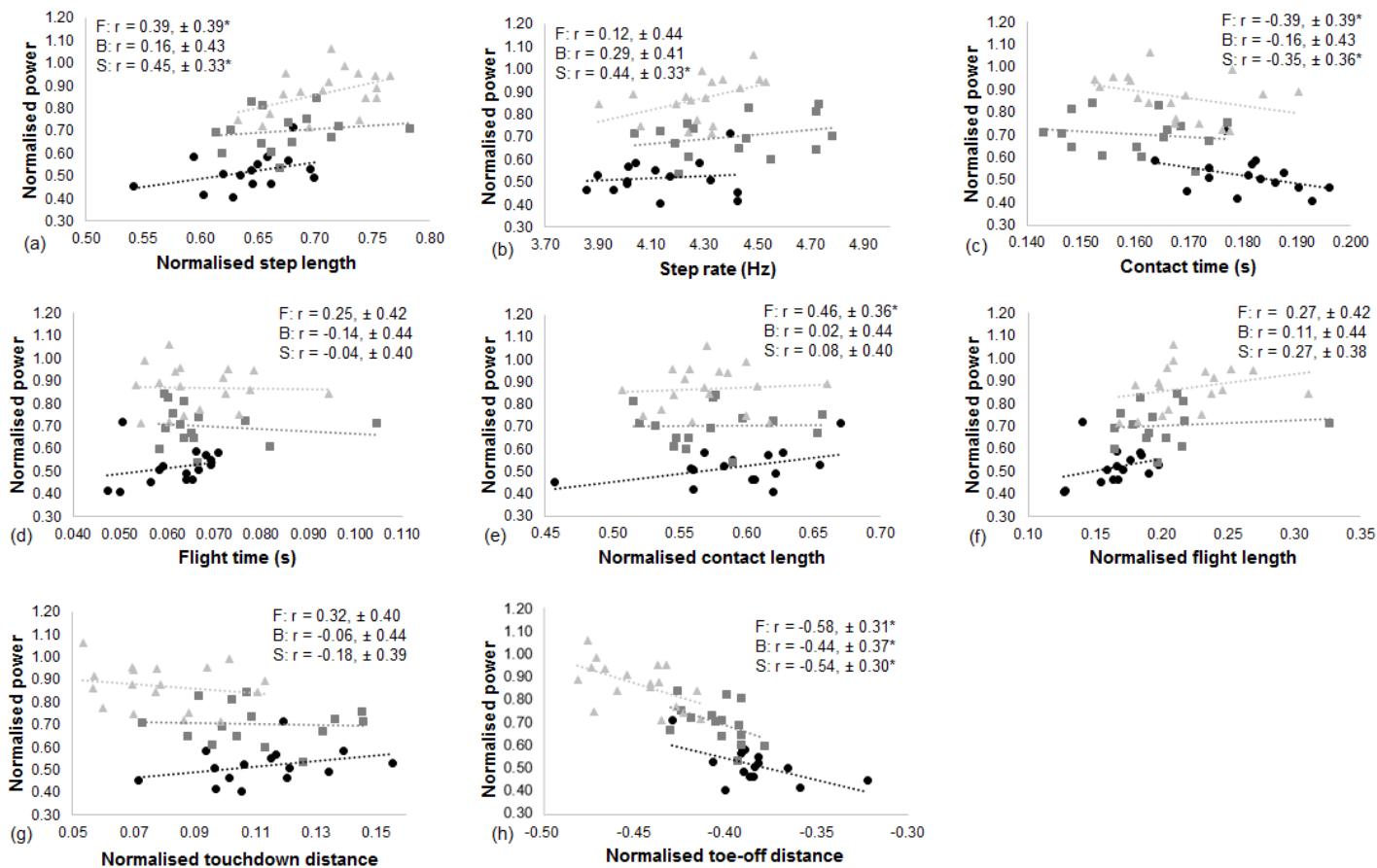618   [c]Below the asterisks.
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623 Figure 2. Step characteristics and linear kinematic variables for rugby forwards (F) and
624 backs (B), and sprinters (S) during the first three steps of a sprint. Individual participant
625 means are plotted, and the black bars represent group means and each participant within
626 each group is represented as an individual data point. The number of asterisks depict the
627 quantitative chances of finding between group differences: * = possibly; ** = likely,
628 *** = very likely, **** = most likely
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Figure 3. Relationships (Pearson's correlation coefficients and their 90% confidence intervals) of step characteristics and linear kinematic variables with average normalised average horizontal external power for forwards (F), backs (B) and sprinters (S) from first touchdown until the end of the third contact phase of a sprint. Black circles = rugby forwards; dark grey squares = rugby backs and light grey triangles = sprinters. Asterisks indicate clear relationships where confidence limits do not overlap substantial positive and negative values (i.e. r = ± 0.1; Hopkins, 2002).